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PROSPECTS FOR WEAK LENSING STUDIES WITH NEW RADIO TELESCOPES

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I consider the prospects for performing weak lensing studies with the new generation of radio telescopes that are coming online now and in the future. I include a description of a proposed technique to use polarization observations in radio weak lensing analyses which could prove extremely useful for removing a contaminating signal from intrinsic alignments. Ultimately, the Square Kilometre Array promises to be an exceptional instrument for performing weak lensing studies due to the high resolution, large area surveys which it will perform. In the nearer term, the e-MERLIN instrument in the UK offers the high sensitivity and sub-arcsec resolution required to prove weak lensing techniques in the radio band. I describe the SuperCLASS survey – a recently accepted e-MERLIN legacy programme which will perform a pioneering radio weak lensing analysis of a supercluster of galaxies.

1 Weak lensing in the radio band

Weak gravitational lensing is the coherent distortion in the images of faint background galaxies due to gravitational light deflection caused by intervening (dark) matter distributions. On the very largest scales, the effect traces the large scale structure of the Universe and is known as cosmic shear. The vast majority of weak lensing surveys to date have been conducted in the optical bands since large numbers of background galaxies are required in order to measure the small ($\sim$ a few %) distortions. However, a new generation of powerful radio facilities is now imminent which makes weak lensing in the radio band a viable alternative.

The only significant measurement of cosmic shear in the radio band to date is the work of Chang et al. (2004) who made a statistical detection in the Very Large Array (VLA) FIRST survey. Recently a further attempt to measure radio weak lensing has been applied to data from the VLA and old MERLIN telescopes (Patel et al. 2010). This latter work did not detect a significant lensing signal precisely because of the small number density of galaxies typically found in radio surveys. However, it was able to assess the feasibility of doing so and also proposed that systematic effects could be removed by observing the same patch of the sky in the radio and optical wavebands. The e-MERLIN and LOFAR facilities, along with the Square Kilometre Array (SKA) precursor telescopes, MeerKAT (Karoo Array Telescope) and ASKAP (Australian Square Kilometre Array Pathfinder), will be of sufficient sensitivity to achieve a comparable source galaxy number density to planned optical surveys. Ultimately, all of these facilities will act as pathfinders for the SKA itself which will conduct all-sky surveys with unprecedented sensitivity in the radio band towards the end of this decade.

Performing weak lensing in the radio band is particularly attractive for a number of reasons. For example, one of the main obstacles facing the optical lensing community is an issue of

instrumental systematics: an exquisite deconvolution of the telescope point spread function (PSF) is required in order to return unbiased estimates of the galaxy shapes. In contrast to complicated and spatially varying optical PSFs, radio telescopes have highly stable and well understood beam shapes. In addition, a definitive weak lensing survey conducted with the SKA would yield precise redshifts for a large fraction of the source galaxies through the detection of their H1 emission line (e.g. Blake et al. 2007). Uncertainties and biases associated with photometric redshift errors would consequently be greatly reduced with an SKA lensing survey.

In addition to instrumental systematics, weak lensing surveys are also subject to serious astrophysical systematics — *intrinsic galaxy alignments*. Galaxies are expected to exhibit some degree of alignment in their orientations due to the tidal influence of large-scale structure during the galaxy formation process. These intrinsic alignments can mimic a cosmic shear signal and represent one of the biggest challenges for precision cosmology measurements using weak lensing.

With this in mind, a unique advantage offered by measuring lensing in the radio band is the polarization information which is usually measured in addition to the total intensity in radio surveys. Previous authors have exploited the fact that the polarization position angle is unaffected by lensing in order to measure gravitational lensing of distant quasars (Kronberg et al. 1991, 1996; Burns et al. 2004). In a recent paper with R. Battye (Brown & Battye 2011a), I showed how one could extend this idea to measure cosmic shear. The technique relies on there existing a reasonably tight relationship between the orientation of the integrated polarized emission and the intrinsic morphological orientation of the galaxy. The existence of this relationship needs to be established for the high-redshift star-forming galaxies which are expected to dominate the radio sky at the μJy flux sensitivities achievable with forthcoming instruments. However, such a relationship certainly exists in the local universe (Stil et al. 2009) and it is reasonable to assume that it persists to higher redshift. A key difference between the polarization technique and standard techniques for measuring lensing is that the former does not assume that the ensemble average of the intrinsic shapes of galaxies vanishes. It is thus, in principle, able to cleanly discriminate between a lensing signal and a possible contaminating signal due to intrinsic galaxy alignments (Brown & Battye 2011a).

Fig. 1 demonstrates the potential power of this technique in terms of its ability to mitigate intrinsic alignments. The figure shows the bias in the recovered weak lensing power spectra in simulations of a future SKA-like survey in the presence of a contaminating signal from intrinsic alignments. For these simulations, we assumed that the orientation of the polarized emission is an unbiased tracer of the intrinsic structural position angle with a scatter of 5 degs and that we can measure the polarization in 10% of the total galaxy sample.

2 The SuperCLASS survey

e-MERLIN, the UK's next generation radio telescope, has now been commissioned and has recently begun science operations. It consists of seven radio telescopes, spanning 217 km, connected by a new optical fibre network to Jodrell Bank Observatory near Macclesfield in the UK. Of the present (or soon to be available) radio instruments e-MERLIN has a number of advantages for detecting weak lensing in the radio band. Most significant of these is the fact that it has very high resolution (≈ 0.2 arcsec at L-band) making it possible to detect the ellipticity of individual sources since they have similar angular extent to that detected in the optical (Muxlow et al., 2005). The SuperCLuster Assisted Shear Survey (SuperCLASS; P.I. R. Battye) was recently approved as an e-MERLIN legacy project to pursue the objective of performing weak lensing analyses in the radio band. SuperCLASS will survey a 1.75 degs^2 region of sky with 0.2 arcsec at 1.4 GHz to an unprecedented r.m.s. sensitivity level of 4 μJy bm^{-1}. In addition to performing a standard weak lensing analysis, these data will allow us to perform the first demonstration of the polarization lensing techniques described above on real data.

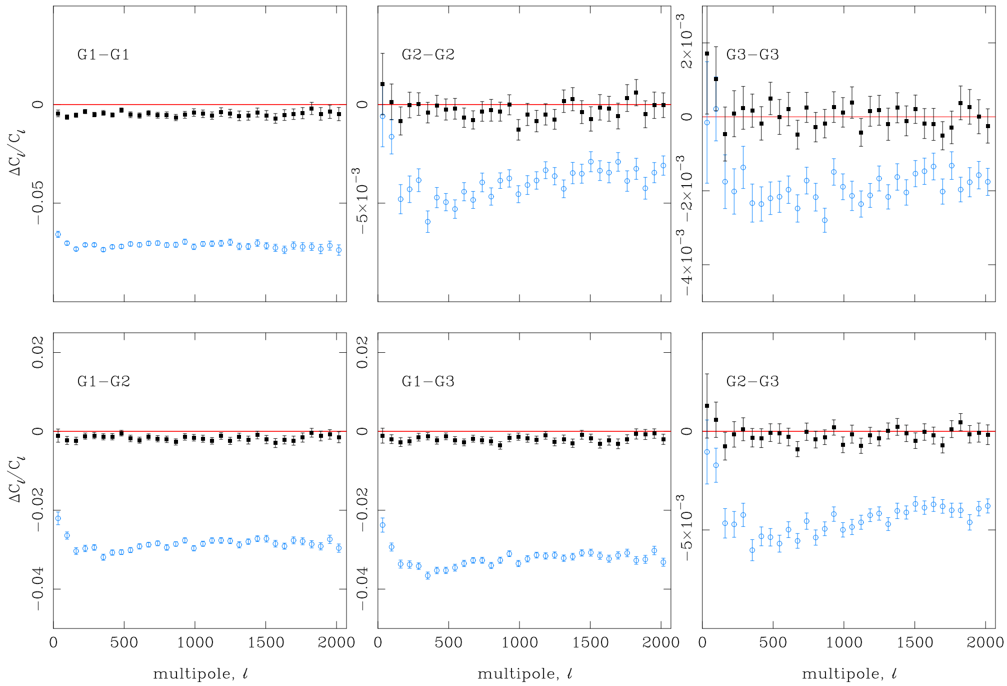

Figure 1: Fractional bias ($\Delta C_\ell / C_\ell$) in the simulated reconstruction of the shear auto- and cross-power spectra in three redshift bins in the presence of a contaminating signal from intrinsic alignments. The top panels show the residuals in the auto-power spectra in the three redshift bins (increasing in redshift from left to right). The bottom panels show the cross-power residuals. The light blue points show the result obtained using a standard lensing analysis and shows a clear bias due to the intrinsic alignment effect. The black points show the recovery obtained with an analysis using polarization information where the bias is reduced by an order of magniutde.

The presently chosen target is a region containing 5 Abell clusters at right ascension ≈ 14 hours and declination ≈ 68 degs with measured redshifts ≈ 0.2. All five clusters (A968, A981, A998, A1005, A1006) have been detected by ROSAT with luminosities compatible with them having masses in the range $(1-2)\times 10^{14}$ $\mathrm{M}_\odot$. We expect to be able to detect the weak lensing effect of these clusters and also from some of the large-scale filamentary structure expected to permeate the regions between the clusters.

Fig. 2 shows a simulation of how well we might expect to recover the dark matter distribution in the region of the supercluster. It shows reconstructions of the dark matter distribution in a randomly chosen 1.75 deg^2 region of simulated sky as seen in the N-body simulations of White (2005). The projected mass reconstructions were performed using the algorithms described in Brown & Battye (2011b) which extended standard mass-reconstruction techniques to include potential information coming from polarization observations. The reconstructions are presented for sensitivity levels approximating the SuperCLASS survey and for a sensitivity level approximating what one might expect to achieve with the SKA.

3 Conclusion

I have given a brief summary of the status of the field of weak lensing in the radio band. While it currently lags well behind the field of optical weak lensing, the new radio instruments coming online now make radio weak lensing a viable alternative which is complementary to large scale optical surveys. In particular, radio polarization observations offer interesting possibilities for removing intrinsic alignments from radio lensing surveys. Over the course of the next few years, the SuperCLASS survey on the e-MERLIN telescope will act as a pathfinder experiment for more ambitious radio lensing surveys with future instruments.

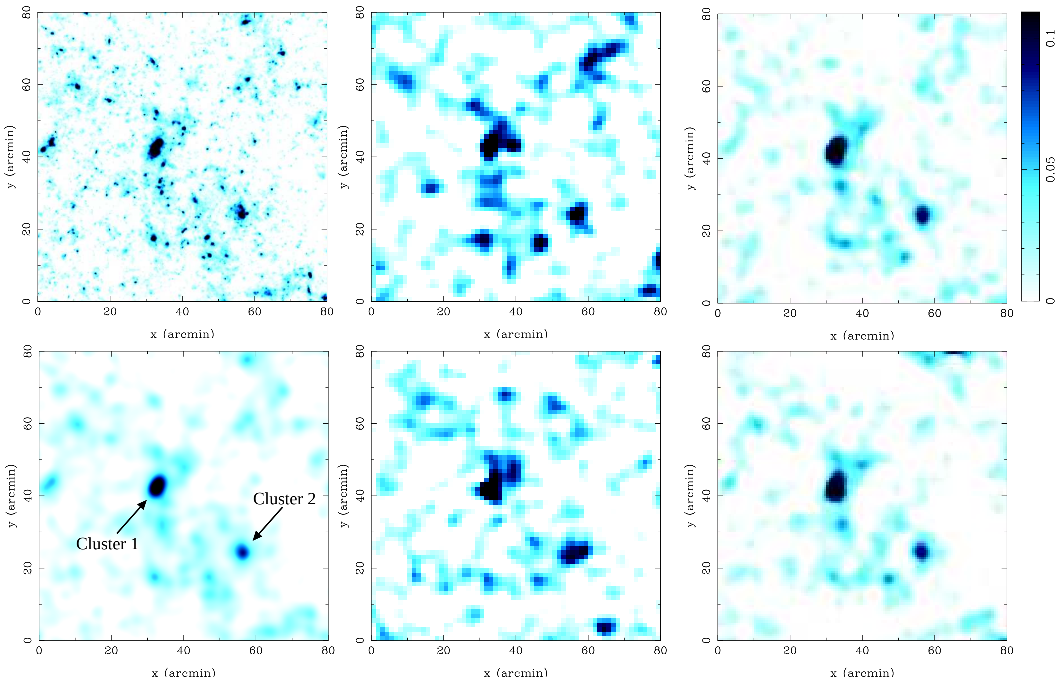

Figure 2: Simulation of the recovery of the dark matter distribution in a randomly selected simulation designed to mimic the SuperCLASS survey and a future SKA survey. The input distribution is shown in the top-left panel and shown smoothed in the bottom left. The middle panels show the recovery for a SuperCLASS-like survey with e-MERLIN and the right hand panels show the simulated recovery for future surveys with the SKA. The top panels show the recoveries obtained using a standard lensing analysis. The bottom panels show the recovery obtained using the polarization technique.

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